VERIFICATION OF TRANSLATION

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[TITLE OF INVENTION] Optical Amplifier Device and Optical Amplifying Method
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[Claim 1]
An optical amplifier device characterized by being equipped with an optical amplification medium that amplifies light, an excitation method for stimulating said optical amplification method so as to generate at least one gain peak, and a gain equalizer that equalizes the gain of said optical amplification medium, where said gain equalizer performs equalization such that gain is produced in the optical wavelength domain of said optical amplification medium wherein the gain is not maximized.

[Claim 2]
An optical amplifier device characterized by being equipped with an optical amplification medium that amplifies light, an excitation method for stimulating said optical amplification method so as to generate at least one gain peak, and a gain equalizer that equalizes the gain of said optical amplification medium in said optical amplification medium as a whole, where said gain equalizer performs equalization such that gain is produced in the optical wavelength domain of said optical amplification medium wherein the gain is not maximized.

[Claim 3]
An optical amplifier device characterized by being equipped with multiple optical amplification media for amplifying the light, an excitation method for stimulating the multiple optical amplification media so as to produce at least one gain peak, and multiple gain equalizers that equalize the gain of said optical amplification media between the multiple optical amplification media, where the multiple gain equalizers amplify the light in the wavelength region where the gain that is generated by the multiple light amplification media and the excitation method is not maximized.

[Claim 4]
An optical amplification method characterized by being equipped with an optical amplification medium doped with rare earth elements, where an excitation light source for exciting the rare-earth elements in said optical amplification medium and a gain equalizer device that equalizes the wavelength characteristics of the optical amplification gain that is generated by the excitation of said amplification medium by the excitation light source, where said optical excitation light source has a population inversion ratio wherein gain is generated in the wavelength band of the signal that is amplified by said amplification medium, where the wavelength band of the signal that is amplified by said amplification medium uses a band that does not include the maximum value of the gain that is generated by said optical amplification medium by said excitation light source, where said gain equalizer device attenuates the maximum value of the gain in said optical amplification medium.

[Claim 5]

The optical amplification device of Claims 1 through 3, characterized by monitoring the inputs and outputs of said optical amplification medium (media), and applying feedback to the excitation method in order to keep the gain of said optical amplification medium (media) to a specific value.

[Claim 6]
The optical amplification device of Claims 1 to 3, characterized by the provision of a resonator(s) containing said optical application medium (media).

[Claim 7]
The optical amplifier device of Claims 1 through 3, characterized by said optical amplification medium (media) being an optical amplifier device(s) wherein the excitation causes excited emissions within the medium (media).

[Claim 8]
An optical amplifier device characterized by the optical amplification medium being excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.7 and 1, where said amplifying media performs equalization distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1490 nm and 1530 nm and the wavelength of the excitation light source.

[Claim 9]
An optical amplifier device characterized by the optical amplification medium being excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.8 and 1, where said amplifying media performs equalization distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1450 nm and 1490 nm and the wavelength of the excitation light source.

[Claim 10]
An optical amplifier device characterized by the optical amplification medium being excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.3 and 1, where said amplifying media performs equalization distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1610 nm and 1650 nm and the wavelength of the excitation light source.

[Claim 11]
An optical amplification method characterized by selecting the population inversion ratio of an optical amplification medium and expanding the band over which there is gain generated by said optical amplification medium to set the wavelength bands that are used in optical telecommunications to a position that differs from the gain peak value generated by said optical amplifier material, equalizing the gain so that the gain will be even over the wavelength band used in said optical telecommunications, and attenuating

wavelength bands for which there is gain in the optical amplification medium in regions except for those wavelength bands used in said optical telecommunications.

[Claim 12]
An optical amplifier device characterized by being equipped with an optical amplification medium that has at least one amplification gain peak and wherein there is population inversion by the excitation, and provided with an equalizer that equalizes the gain characteristics of said amplification medium so as to obtain a nearly even gain band at frequencies lower than the peak value of said amplification gain.

[Simple Explanation of the Invention]
[0001]
[Industrial Field to Which the Invention Belongs]
This invention has to do with optical amplifier devices that amplify optical-wavelength composite optical signals that are composites of multiple optical signals with different wavelengths, and has to do with optical communications systems wherein the multi-wavelength composite optical signals are relayed multiple times through multiple optical amplifier relays, and in particular, this invention has to do with optical amplifier devices having new bands that have not existed conventionally.

[0002]
[Prior Art]
The band over which losses are low in optical fiber transmission circuits (less than approximately 0.3 dB/km) is the band from 1450 nm to 1650 nm, and a variety of optical fiber amplification devices, as shown in Figure 1, have been developed for this transmission band.

[0003]
At present, the effects of the popular acceptance of portable telephones and the rapid increase in Internet services, the demand for telecommunications capacity is expanding explosively, and there are intense efforts globally into the research and development of technologies that can increase the capacity that can be transmitted on a single fiber.

[0004]
At present, the optical wavelength composite technology that uses the broadband characteristics of optical fiber amplifier equipment using silica erbium-doped fibers (EDF) has become a critical technology, and the wavelength band is known as both the 1550 nm band (1530 to 1560 nm) or the C-band (Conventional-wavelength band).

[0005]
In addition, for EDF, optical fiber amplifier equipment for the 1580 nm band (1570 to 1600 nm) and the L-band (Longer-wavelength band) have been developed, and competition has become intense in developing a commercial optical fiber telecommunications system that is able to transmit ultra large capacities of a total of 1.6 terabit/s by modulating each wavelength at 10 Gb/s with about 80 waves in each of the band for a total composite of 160 waves.

[0006]
Because there is a capacity of approximately eight THz when C-band and L-band are combined, when 10 Gb/s transmission signal channels are established with the 100 GHz spacing recommended by ITUT, the overall transmission capacity of 1.6 terabit can be expanded further, although there is a limit at about 6 Tb/s.

[0007]
On the other hand, there is demand for even greater carrying capacity, and so optical fiber amplification devices that have new optical amplification bands in addition to the recurrent C-band and L-band optical amplification devices are required.

[0008]
In Figure 1, even though GS-TDFA (gain-shifted thulium-doped fluoride-based fiber amplifiers) are being developed as the fibers for amplification in the S-band region from 1490 nm to 1530 nm, the region where there is gain in the region between 1475 and 1510 nm, and thus it is difficult to succeed in amplification in the S-band region from 1510 to 1530 nm.

[0009]
In addition, the 1610 to 1650 nm band is limited to specialty fibers that are either thulium or terbium-doped fluoride-based fibers.

[0010]
In the optical amplifier device as explained above, the part that is used for the optical amplification medium amplifies the light through excited emissions through an inverted population of the energy levels through excitation of the part that serves as the optical amplification medium.

[0011]
There is also Raman fiber amplification, which uses the non-linear effects of fibers.

[0012]
Because Raman fiber amplification makes use of non-linear effects of fibers, it has the benefit of having a gain in any given wavelength band by selecting the wavelength of the stimulating light sources; however, there are problems in that the gain per unit length is small, so fibers for optical amplification are required every several kilometers or every several dozen kilometers, making miniaturization difficult.

[0013]
[Problem This Invention Attempt to Solve]
In this invention the excited emissions resulting from energy population inversions formed in the optical amplification medium by excitation outside of the Raman fiber amplification (optical amplification that uses non-linear effects) in optical amplification devices (rare-earth-element-doped fiber amplification devices or semiconductor optical amplification devices (SOA)) are used to provide optical fiber amplification devices that

have amplification bands in 1450 to 1490 nm S+- band, the 1490 to 1530 nm S-band, or the 1610 to 1650 nm L+- band.

[0014]

[Method for Solving the Problem]

As the No. 1 method, an optical amplification medium that amplifies light, an excitation method for stimulating said optical amplification method so as to generate at least one gain peak, and a gain equalizer that equalizes the gain of said optical amplification medium, are provided to perform equalization such that gain is produced in the optical wavelength domain of said optical amplification medium wherein the gain is not maximized.

[0015]

As the No. 2 method, an optical amplification medium that amplifies light, an excitation method for stimulating said optical amplification method so as to generate at least one gain peak, and a gain equalizer that equalizes the gain of said optical amplification medium in said optical amplification medium as a whole, are provided to perform equalization such that gain is produced in the optical wavelength domain of said optical amplification medium wherein the gain is not maximized.

[0016]

As the No. 3 method, multiple optical amplification media for amplifying the light, an excitation method for stimulating the multiple optical amplification media so as to produce at least one gain peak, and multiple gain equalizers that equalize the gain of said optical amplification media between the multiple optical amplification media, are provided to amplify the light in the wavelength region where the gain that is generated by the multiple light amplification media and the excitation methods is not maximized.

[0017]

As the No. 4 method, an optical amplification medium doped with rare earth elements, an excitation light source for exciting the rare-earth elements in said optical amplification medium and a gain equalizer device that equalizes the wavelength characteristics of the optical amplification gain that is generated by the excitation of said amplification medium by the excitation light source are provided where said optical excitation light source has a population inversion ratio wherein gain is generated in the wavelength band of the signal that is amplified by said amplification medium, where the wavelength band of the signal that is amplified by said amplification medium uses a band that does not include the maximum value of the gain that is generated by said optical amplification medium by said excitation light source, where said gain equalizer device attenuates the maximum value of the gain in said optical amplification medium.

[0018]

As the No. 5 method, in methods 1 to 3 the inputs and outputs of said optical amplification medium (media) are monitored, and feedback to the excitation method is applied in order to control to a specific value the gain of said optical amplification medium (media).

[0019]
As the No. 6 method, a resonator(s) containing said optical application medium (media) is (are) provided in methods 1 to 3.

[0020]
As the No. 7 method, the optical amplification device of claims 1 to 3, characterized by said optical amplification medium (media) being an optical amplifier device(s) wherein the excitation causes excited emissions within the medium (media) in methods 1 to 3.

[0021]
As the No. 8 method, an optical amplifier device where the optical amplification medium is excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.7 and 1, where equalization is performed in said amplification medium distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1490 nm and 1530 nm and the wavelength of the excitation light source.

[0022]
As the No. 9 method, an optical amplifier device where the optical amplification medium is excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.8 and 1, where equalization is performed in said amplification medium distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1450 nm and 1490 nm and the wavelength of the excitation light source.

[0023]
As the No. 10 method, an optical amplifier device where the optical amplification medium is excited so that the population inversion rates of the optical amplification medium, made from erbium-doped fiber, are at a ratio between 0.3 and 1, where equalization is performed in said amplification medium distributively or dispersively so that there will be nearly identical wavelength characteristics in said wavelength band passing through the wavelength band between about 1610 nm and 1650 nm and the wavelength of the excitation light source.

[0024]
As the No. 11 method, an optical amplifier optical amplification method selects the population inversion ratio of an optical amplification medium and expands the band over which there is gain generated by said optical amplification medium to set the wavelength bands that are used in optical telecommunications to a position that differs from the gain peak value generated by said optical amplifier material, equalizing the gain so that the gain will be even over the wavelength band used in said optical telecommunications, and attenuating wavelength bands for which there is gain in the optical amplification medium in regions except for those wavelength bands used in said optical telecommunications.

[0025]
As the No. 12 method, an optical amplifier device is structured with an optical amplification medium that has at least one amplification gain peak and wherein there is population inversion by the excitation, and an equalizer is structured so that equalizes the gain characteristics of said amplification medium so as to obtain a nearly even gain band at frequencies lower than the peak value of said amplification gain.

[0026]
[Embodiments of the Invention]
Figure 2 shows the wavelength characteristics of the relative gain coefficients in various population inversion rates of silica erbium-doped fiber (EDF).

[0027]
The population inversion rates are defined by the proportion of the erbium ions that are excited, where this rate goes to 1.0 when all of the ions are excited (i.e., when all electrons are excited to the higher levels), and if none of the ions are excited (i.e., all are in the non-excited level), then the population inversion ratio is 0.0.

[0028]
The relative gain coefficient on the vertical axis is the gain per unit length.

[0029]
At present, multi-wavelength optical fiber amplifiers using silica-based erbium-doped fibers (EDF) for high-capacity uses pump the silica-based erbium-doped fiber EDF population inversion rates up to about 0.7 so that the amplification band is in the 1550 nm band (1530 to 1570 nm), and then use the silica-based erbium-doped fiber (EDF)

[0030]
Then the band wherein the gain is the greatest is used, and a gain equalizer is used as well to produce an even gain that is independent of the wavelength.

[0031]
As with C-band, multi-wavelength optical amplifiers that amplify the long-wavelength L-band (1560 to 1610 nm) are nearing the level for commercialization.

[0032]
In these optical amplifiers, the population inversion rates are dropped on purpose to about 0.4 in the silica-based erbium-doped fibers (EDF) to construct an L-band optical amplifier by producing a gain that is both equalized and maximized for the gain per unit length for the long-wavelength band (L-band).

[0033]
This L-band optical amplifier that uses silica-based erbium-doped fibers (EDF) produces the required gain by using longer EDF lengths because, as is shown in Figure 2, the gain for a given EDF length is less than the gain for C-band optical amplifiers that use EDF.

[0034]
When one looks closely at the wavelength characteristics of the gain in Figure 2 when the population inversion ratio is put to, for example, 0.9, it can be seen that high gains are achieved in bands where they have not been achieved before, such as the 1450 to 1530 nm band or the 1610 to 1650 nm band.

[0035]
However, because the per-unit length gain for the C-band (1530 to 1570 nm) is large when the population inversion ratio is 0.9, the amplification effect is dominated by the C-band.

[0036]
Because of this, in this invention a gain equalizer (GEQ) is used to suppress the C-band.

[0037]
Figure 3 extracts the gain/wavelength characteristics for the 0.9 population inversion ratio case from Figure 2, and shows the per-unit length gain characteristics when the S-band gain is extracted and equalized.

[0038]
When the population inversion ratio in Figure 3 is at 0.9, there is a gain peak in the vicinity of 1530 nm.

[0039]
When the area of the gain peak that is marked by the diagonal lines is eliminated, then there will be gain equalization such that, in the S-band, there will be flat gain characteristics as shown by the white cutout rectangle area, and the other wavelength bands are eliminated.

[0040]
Using this method, not only is the large per-unit-length gain in the C-band cut by the equalizer, but also the per-unit-length gain for the S-band is reduced because of the equalization for flattening the gain in the S-band for ease in wave domain multiplexing of the transmitted signal light.

[0041]
However, the per-unit-length gain for the L-band optical amplifiers that amplify the light using the 0.4 population inversion ratio of Figure 2 can produce a large gain.

[0042]
In other words, when one considers that it is possible to create a practical optical fiber amplifier in the L-band, gain equalization is performed in order to obtain flattened gain characteristics at points that are different from the location of the peak value in the center of this band (i.e., on the periphery of the gain characteristics) by increasing the population inversion ratio in the amplification medium and spreading the band over

which gain is produced in the optical amplification medium, and in order to obtain the desired gain, the length of the optical amplification medium and the gain equalizer are selected based on the gain characteristics at the population inversion rates of the energy of the optical amplification in order to produce an optical amplifier that has practical gain in the S-band, the S+- band, and the L+- band using silica-based erbium-doped fibers (EDF).

[0043]
In particular, when we consider the characteristics of the population inversion rates in relation to gain and wavelength for fibers that are doped with erbium, these fibers are more effective than the existing C-band amplifiers and L-band amplifiers in creating optical amplifiers that are able to produce nearly flat wavelength bands on the short wavelength side.

[0044]
Figure 4 shows the wavelength characteristics of a gain equalizer (GEQ, an "optical filter") in the S-band.

[0045]
The structure is such that there is a transmittance region in the band between 950 nm and 1000 nm so that the 980 nm excitation light source can pass through, and in the 1490 nm to 1530 nm band the transmittance falls as the wavelengths grow longer in order to be able to produce the gain characteristics of the white cut out rectangle in Figure 3 corresponding to the amplification gain.

[0046]
Looking at Figure 4 in terms of Figure 2, Figure 4 shows a structure that suppresses the gain peak that is centered on 1531 nm, which is characteristic of the gain equalizer that been structured; however, for EDF, when a population inversion is selected so that there is gain in the S-band, the peak wavelength will shift between about 1528 nm and 1535 nm depending on the dopant material (materials such as Al or Ge) and depending on the structure of the effective cross-sectional area of the fiber.

[0047]
Consequently, because the gain peak central wavelength will vary depending on the type of amplification medium, the characteristics of the gain equalizer must be caused to match the central wavelength of the gain and the population inversion ratio for each individual amplification medium, and the structure must be such that the amount of equalization is adjusted depending on the wavelength.

[0048]
Figure 5 shows an example of an actual structure for an S-band optical amplifier.

[0049]
In the figure, 1 is a silica-based erbium-doped fiber (EDF), 2 is a gain equalizer (GEQ), 31 and 32 are optical isolators, 4 is the excitation light source, 5 is a multi-wavelength

coupler, 8 is the input terminal, 9 is the output terminal, 71 and 72 are optical splitter couplers, 81 is an input monitor PD, 82 is an output monitor PD, and 50 is a gain control circuit (AGC).

[0050]
The multi-wavelength light that is input through input terminal 8 passes through the optical isolator 31 and the multi-wavelength coupler 5 and is input into the silica-based erbium-doped fiber (EDF) 1, which is the amplification medium that produces excited emissions through excitation.

[0051]
The silica-based erbium-doped fibers (EDF) used here have a 7μm mode field, and Er density of 500 ppm and a fiber length of 150 m.

[0052]
The configuration of the fiber is only one example, and typical EDFs can be used. (Typical EDF mode field diameters of EDF fibers currently on the market range from 5 μm to 8 μm and Er densities range from 100 ppm to 1500 ppm. When it comes to fiber length, the length is adjusted for the amplifier depending on the gain for the amplification and on the density, and can be anywhere in a broad range from 1 m to 10 km.) Furthermore, the fiber length is subject to adjustment depending on the gain to be obtained and the per-unit-length gain in the wavelength band used, which depends on the population inversion ratio.

[0053]
In the silica-based erbium-doped fiber (EDF) 1, the multi-wavelength light that is injected through input terminal 8 is optically amplified by the 0.98 μm excitation light from the excitation light source 4 that was injected through the multi-wavelength coupler 5, and then is input into the gain equalizer 2.

[0054]
At this time, the excitation light power is controlled so that the population inversion ratio in the silica-based erbium-doped fiber 1 will be 0.9 and the wavelength characteristics in Figure 3 are obtained.

[0055]
The gain equalizer 2 fundamentally has the gain equalization characteristics shown in Figure 4, and although the gain equalization is performed to produce gain with the characteristics of the white rectangular cutout in Figure 3, because the gain equalizer 2 is established after the silicon-based erbium-doped fiber (EDF) 1, the excitation need not necessarily be transparent to light.

[0056]
This gain equalizer 2 can be made from combinations of multiple Fabre-Perot etalon filters, multilayer dielectric filters, and/or fiber grating filters.

[0057]
The output of the gain equalizer 2 outputs the amplified light from the output terminal 9 through the isolator 32.

[0058]
The optical splitter coupler 71 on the input terminal side splits a portion of the incident light and inputs it into the input monitor PD 81, and the optical splitter coupler 72 on the output terminal side splits a portion of the light that was amplified by EDF 1 and inputs it into the output monitor PD 82.

[0059]
The automatic gain control circuit (AGC) 50 controls the optical power that is output from the 0.98 μm semiconductor laser that serves as the excitation light source 4 based on the light that was detected at the input monitor PD 81 and the output monitor PD 82 so that the gain of the erbium-doped fiber 1 remains constant. By maintaining the EDF gain at a constant value the population inversion ratio is also maintained at a constant value regardless of the input power.

[0060]
When it is desirable that the output level be controlled to a constant value in addition to having the automatic gain control circuit (AGC) 50, then a variable attenuator is provided at either the input terminal 8 or the output terminal 9, making it possible to control the output of the optical amplifier to a constant value by controlling either the level of the optical signal that is input to the optical amplifier or controlling the level of the optical signal that is output from the optical amplifier, even when the gain of the optical amplifier is controlled to a constant value.

[0061]
The reason why the gain of the automatic gain control circuit (AGC) 50 is controlled so that it remains constant is that the wavelength characteristics would change, as is shown in Figure 2, when there are changes in the gain.

[0062]
Consequently, by adapting to changes in the gain wavelength characteristics of the silica-based erbium-doped fiber EDF through either controlling the angle of incidence or the temperature of the filter within the gain equalizer or through the use of a variable wavelength filter, such as a resonant optic filter, so that the characteristics of the gain equalizer (GEQ) 2 are variable the excitation light power from the excitation light source can be controlled by the automatic level control circuit (ALC) so that the optical amplification output level remains constant by monitoring either the output monitor PD 82 or the input monitor 81 alone.

[0063]
The reason why the 0.98 μm excitation light source is used in Figure 5 is because it is able to raise the population inversion ratio to just about 1 when combined with a conventional EDFA, and insofar as there is gain in the band to be transmitted, a 1.48 μm

band (ranging from 1.45 μm to 1.49 μm) light with good amplification efficiency relative to EDF can be used instead.

[0064]
Although in Figure 5 the explanation was made using forward-direction excitation where the excitation was from the input terminal side of the EDF, and multi-wavelength coupler can be inserted between the gain equalizer 2 and the optical isolator 32 to excite in the backwards directions, stimulating from the EDF output terminal side, or bi-directional excitation, where the excitation light source excites the EDF from both the input terminal side and the output terminal side, can be used.

[0065]
Additionally, in the case of bi-directional excitation, a combination of the 0.98 μm and the 1.48 μm bands can be used as the excitation wavelength.

[0066]
However, the wavelength characteristics of the equalizer must be such that it is possible for the 1.48 band to pass the 0.98 band excitation light. [sic]

[0067]
In this way, when 2 excitation light images [sic] are used, the light source of either wavelength can be used for the forward excitation.

[0068]
In addition, here the excitation light source need not necessarily be just a single semiconductor laser, but a composite of wavelengths or polarizations of light from multiple semiconductor lasers can be outputted.

[0069]
Although a population inversion ratio of 0.9 was used as an example in the example of an S-band optical amplifier in Figure 5, the populations in version rate can be selected to have the gain in the band region used, and gain equalization can be performed to reduce the gain in bands other than those in the band region used, and so an S-band optical amplifier can be structured using population inversion rates ranging from 0.7 to 1 with the optical amplification medium used in Figure 5.

[0070]
Similarly, when structuring an S+- band optical amplifier for the bands between 1450 nm and 1490 nm, a population inversion ratio between 0.8 and 1 can be used.

[0071]
In addition, when structuring an L+- band optical amplifier for the bands between 1610 nm and 1650 nm, a population inversion ratio between 0.3 and 1 can be used.

[0072]

Moreover, because the gains obtained for each band will vary in terms of the gain of the optical amplifier, the length of the EDF (which is the optical amplification medium) must be selected to match the targeted gain.

[0073]
The S-band optical amplifier of this invention is definitively different from L-band optical amplifiers for which the technology has been completed already.

[0074]
When the gain wavelength characteristics of the L-band optical amplifiers that use population inversion rates of about 0.4 (Figure 2) are examined, the gain for the L-band is at its maximum (even though the value itself is small).

[0075]
This is because the excitation light power is converted into an L-band signal spontaneously if the population inversion ratio is held at 0.4 by the gain control circuit (AGC), meaning that the amplifier has a high amplification efficiency in the band of light being amplified.

[0076]
On the other hand, when S-band amplification is performed using amplification fiber and a population inversion ratio of 0.9, with a gain equalizer, it will be necessary to suppress, for example, the C-band (wherein the gain is larger than for the S-band).

[0077]
As is shown in Figure 5, when GEQ2 is provided on the output side then the conversion efficiency of the optical amplifier is extremely poor because the majority of the excitation light power is converted into natural emissions (ASE) outside of the S-band. The conversion efficiency is several percent or lower.

[0078]
In general, the conversion efficiency of optical amplifiers is about 60% in the C-band, but in the L-band conversion efficiencies of about 40% have been achieved.

[0079]
Figure 6 shows an example of embodiment for improving the conversion efficiency relative to the structure in Figure 5.

[0080]
In Figure 6 the amplification medium for obtaining the desired gain is divided into multiple segments, and between each segment is placed a gain equalizer to layout the gain equalizers in a dispersed or distributed manner in the lengthwise direction along the entire amplification medium within the optical amplifier.

[0081]

In the figure, 11, 12, and 13 are silica-based erbium-doped fibers (EDF), 21, 22, and 23 are gain equalizers (GEQ), 31 and 32 are optical isolators, 4 is an excitation light source, 5 is a multi-wavelength coupler, 8 is the input terminal, 9 is the output terminal, 71 and 72 are optical splitter couplers, 81 is the input monitor PD, 82 is the output monitor PD, and 50 is the gain control circuit (AGC).

[0082]
The multi-wavelength light that is injected from the input terminal 8 passes through the optical splitter coupler 71 and the optical isolator, along with the multi-wavelength coupler 5, and is injected into the silica-based erbium-doped fiber (EDF) 1 that is the amplification medium.

[0083]
If this EDF 1 has a length of 50 m in order to obtain the desired gain using a population inversion ratio of 0.9, this EDF 1 is segmented each meter into the silica-based erbium-doped fiber 11, (EDF1) through silica-based erbium-doped fiber 13 (EDF50).

[0084]
After that, each EDF segment is connected, respectively, to GEQ'1, 21 through GEQ'50, 23.

[0085]
At this time, the GEQ' wavelength characteristics of their transmittances are reduced to 1/50 of the transmittance rates (in terms of dB units) in the signal wavelength band of the GEQ (i.e., 1490 to 1530 nm) because 50 of the GEQ' units have been inserted.

[0086]
In the silica-based erbium-doped fiber (EDF) 1, the multi-wavelength light that is injected through the input terminal 8 is amplified by the 0.98 μm excitation light from the excitation light source 4 that is injected through the multi-wavelength coupler 5, and is injected into the gain equalizer 2.

[0087]
At this time, the power of the excitation light in the silica-based erbium-doped fiber 1 performs excitation in order to obtain the wavelength characteristics such as shown in Figure 3 at a population inversion ratio of 0.9.

[0088]
The gain equalizers 21 through 23, as a whole, has the gain equalization characteristics shown in Figure 4, giving the gain of the silica-based erbium-doped fiber (EDF) 1 the characteristics shown by the white rectangular cutout in Figure 3, and the gain equalization is performed so that the excitation light is transmitted and the amplified light is output through the optical isolator 32 from the output terminal 9.

[0089]

The individual gain equalizers may each have its own unique equalization characteristics, and even if they have the same equalization characteristics, the characteristics obtained as the final result should be as the characteristics shown in Figure 4.

[0090]
The gain equalizers 21 through 23 can be created by a combination of Fabry-Perot etalon filters and dielectric multilayer filters, or fiber grating filters.

[0091]
The input-side optical splitter coupler 71 splits off a portion of the incident light and injects it into the input monitor PD 81, while the output-side output splitter coupler 72 splits off a portion of the light that was amplified by the EDF1 and injects it into the output monitor PD.

[0092]
The automatic gain control circuit (AGC) 50 controls the optical power that is output from the 0.98 μm semiconductor laser that is the excitation light source 4 based on the light that is detected by the input monitor PD and the output monitor PD to maintain the gain of the optical amplifier (or, more strictly speaking, the gain of the EDF) at a constant value.

[0093]
Here the control in order to keep the gain constant is because variation in the gain causes variations in the wavelength characteristics.

[0094]
Consequently, insofar as it is an equalizer wherein the characteristics of the gain equalizer (GEQ) 2 can be changed and wherein it can accommodate changes in the wavelength characteristics due to changes in the gain by the EDF, then the control can be performed through an automatic level control circuit (ALC) such that the output level is kept constant by monitoring either the output monitor PD 82 or the input monitor 81 alone.

[0095]
In addition, when it is desirable to perform control so that the output level is constant while maintaining the wavelength characteristics of the gain through the use of the automatic gain control circuit (AGC) 50, a variable attenuator can be equipped as the input terminal 8 or the output terminal 9 so that the output of the optical amplifier can be maintained at a constant level through controlling either the optical signal level that is injected into the optical amplifier or the output of the optical amplifier even if the gain of the optical amplifier is controlled to a constant gain.

[0096]
In Figure 6, a 0.98 μm excitation light source was used; however, a 1.48 μm excitation light source may be used instead.

[0097]
Furthermore, the explanation of Figure 6 used forward excitation to excite the EDF from the input terminal side, a multi-wavelength coupler can be equipped between the optical isolator 32 and the gain equalizer 23 to allow backwards excitation from the output terminal side of the EDF or bi-directional excitation, providing excitation to the EDF using the excitation light from both the input terminal side and the output terminal side of the EDF.

[0098]
Furthermore, when bi-directional excitation is used a 0.98 μm excitation light source and a 1.48 μm excitation light source can be used.

[0099]
In this case, the excitation light with either wavelength can be used as the forward excitation.

[0100]
In addition, here the excitation light source is not necessarily only a single semiconductor laser, but rather a composite of wavelengths and polarizations of light output by multiple semiconductor lasers can be outputted.

[0101]
In addition, when it is necessary for the population inversion ratio to be high, (such as 1), then high levels of optical power are required in the excitation light source, and thus a structure wherein multi-wavelength couplers are equipped between each EDF segment and forward excitation, backwards excitation, or bi-directional excitation can be performed on each.

[0102]
Although a population inversion ratio of 0.9 was used as an example in the example of an S-band optical amplifier in Figure 6, the populations in version rate can be selected to have the gain in the band region used, and gain equalization can be performed to reduce the gain in bands other than those in the band region used, and so an S-band optical amplifier can be structured using population inversion rates ranging from 0.7 to 1 with the optical amplification medium used in Figure 6.

[0103]
Similarly, when structuring an S+- band optical amplifier for the bands between 1450 nm and 1490 nm, a population inversion ratio between 0.8 and 1.0 can be used.

[0104]
In addition, when structuring an L+- band optical amplifier for the bands between 1610 nm and 1650 nm, a population inversion ratio between 0.3 and 1.0 can be used.

[0105]

In the section below, the structure of Figure 5 will be compared to the structure of Figure 6 to explain the improvement in the conversion rate of the excitation light power into S-band signal light.

[0106]
In the optical amplifier in Figure 5 the ASE shaped as shown in Figure 3 is extremely large, and because the portion that is shown with the diagonal lines is eliminated by the GEQ, the excitation power is converted into unnecessary ASE, which is a tremendous waste.

[0107]
On the other hand, even though in Figure 6, of course, the ASE shaped as shown in Figure 3 is generated, it is shaped by the GEQ before it is amplified to high powers (or in other words, the unneeded part is removed before amplification), leading to improved efficiencies.

[0108]
When this is expressed quantitatively, if we assume the total ASE power in Figure 5 (i.e., for the total area) is 100 mW, and we eliminate the part shown with the diagonal lines (which we assume to be 90%), then about 90 mW is thrown away. (In other words, this 90 mW has been converted from the excitation light, so, at the very least, 90 mW of excitation light power has been thrown away.)

[0109]
Because the white rectangular cutout area is in the signal band, it cannot be eliminated.

[0110]
In Figure 6, if, for example, about 1/50 of the ASE power (area) is 2 mW, then even if 90% is thrown away, at most 1.8 mW has been thrown away.

[0111]
The critical point here is that the 1.8 mW ASE that is generated in the silica-based erbium-doped fiber 11 (EDF1) causes excited emissions in the next stage if it is not eliminated using the GEQ, causing the excitation light power to be wasted.

[0112]
In other words, placing a single GEQ on the output side, as shown in Figure 5, does nothing but cause the waste ASE to grow, after which it is eliminated by the GEQ.

[0113]
On the other hand, in Figure 6, the ASE is eliminated when it has only grown slightly, making it possible to use that part of the excitation energy that had been used for amplifying the ASE further from the ASE that had been generated, applying it instead to amplification energy for the signal, thereby improving the conversion efficiency.

[0114]

In this way, segmenting the EDF and inserting low-loss GEQs between the segments increases the conversion efficiency.

[0115]
The key to improvement in the conversion efficiency is the selection of the position of the GEQs in the lengthwise direction of the fiber for amplification.

[0116]
As a change in Figure 5, the silica-based erbium-doped fiber can be divided into two segments, and a gain equalizer can be placed between the two segments to produce the characteristics shown by the rectangular cutout in Figure 3 at the final output.

[0117]
With this structure it is possible to improve the efficiency of conversion into an S-band signal light from the excitation light power, over the efficiency in the structure where a single gain equalizer is placed on the output side.

[0118]
Although Figures 5 and 6 use an example where existing silica-based EDFs are used, other different structures can be used where distributed gain equalizers are structured as shown in Figure 7 when the Er additive density is increased, the fiber length is shortened, or an optical wave guide is used.

[0119]
Figure 7 shows a shortened fiber or an Er-doped optical wave guide where the density of the added erbium element per-unit-length is increased and a chlorinated material is used as the base material.

[0120]
Figure 14 shows the core, Figure 15 shows the cladding, and Figure 16 shows the grating.

[0121]
In Figures 5 and 6 the EDF has a mode field diameter of 7 μm and the Er element is doped at 500 ppm. At this time the population inversion ratio is set a 0.9, requiring the total length of the EDF to be about 150 m in order to obtain the target gain of about 20 dB.

[0122]
Consequently, if the fiber or the wave guide substrate base material used high density Er doping of 15×10^5 ppm, then a total length of 5 cm would be adequate to receive the same gain.

[0123]
If, in this way, the length traversed by the light is 5 cm, then the grating 16 that functions as the GEQ to perform the gain equalization so as to attenuate the wavelengths that are outside of the wavelength band for which the amplification is to be performed such as

shown in Figure 6 is formed in the optical fiber or optical wave guide core part 14. In such a case, it is important to use a technology such as the long-period grating technology so that the light that is eliminated by the GEQ is not returned to the core to cause resonance. In other words, when the light that is removed from the GEQ is returned into the core, it structures a resonator within the Er-doped fiber that is the amplification medium, leading to unstable operation due to resonance or to unwanted laser emissions. It is necessary to create and install the GEQs to avoid this situation.

[0124]
At this time, the gratings can be placed in multiple locations such as shown in Figure 6 and can be placed in all of core 14.

[0125]
When such a structure is used, it is possible to obtain the same effect as when the number of grating partitions in Figure 6 was infinitely large.

[0126]
By structuring as shown in Figure 7, it is possible to structure an optical amplifier with excellent optical effects similar to when the GEQs were located in a distributed pattern such as shown in Figure 6.

[0127]
Figure 8 shows the gain-wavelength characteristics when there are changes in the excitation current of the semiconductor optical amplifier.

[0128]
When a semiconductor optical amplifier is used, a bias current is used as the excitation source rather than light.

[0129]
As can be seen in Figure 8, the semiconductor optical amplifier has an amplification peak, and by changing the population inversion ratio by changing the excitation current the wavelength position of the amplification peak and the gain are changed, and the gain-wavelength characteristics are changed.

[0130]
Consequently, as with the use of EDF, the electrical current value is selected so that the population inversion ratio will be such that the gain is maintained in the band region that amplifies the light (or in other words that the gain is held constant), so by using multiple gain equalizers to equalize the gain that is produced by the optical amplification in the unneeded band ranges it is possible to produce an optical amplifier that has an excellent conversion ratio in a band outside of the band where the gain is the greatest.

[0131]
Figure 9 shows a specific example of the structure of an optical amplifier in a semiconductor optical amplifier.

[0132]
Although the specific structure is the same as the structure in Figure 6, multiple semiconductor amplifiers 33, 34, and 35 are used instead of EDF1.

[0133]
The multi-wavelength light that is injected from input terminal 8 passes through the optical splitter coupler 71 and the optical isolator, and is injected into the semiconductor optical amplifiers (SOA) 33 through 35, which comprise the amplification media.

[0134]
Here the semiconductor optical amplifiers (SOA) required in order to obtain the specific gain in the target wavelength band are established in multiple stages.

[0135]
In addition, gain equalizers 21 (GEQ' 1) through gain equalizer 23 (GEQ' 50) are connected between the respective semiconductor amplifier segments.

[0136]
At this time, the GEQ' transmittance wavelength characteristics are such that the transmittance characteristics (in units of dB) for the amount of gain equalization is divided by the number units (relative to the equalization that is performed all at once in the final stage such as shown in Figure 5) because multiple GEQ' units have been inserted.

[0137]
The individual gain equalizers may each have its own unique equalization characteristics, and even if they have the same equalization characteristics, the characteristics obtained as the final result should be such that a flat gain region is obtained in the target band.

[0138]
The gain equalizers 21 through 23 can be created by a combination of Favry-Perot etalon filters and dielectric multilayer filters, or fiber grating filters.

[0139]
The input terminal-side optical splitter coupler 71 splits off a portion of the incident light and injects it into the input monitor PD 81 and the output terminal-side output splitter coupler 72 splits off a portion of the light that has been amplified by the semiconductor amplifiers SOA 33 - 35 and injects it into the output monitor PD.

[0140]
The automatic gain control circuit (AGC) 50 controls the bias level of the excitation current for semiconductor optical amplifiers SOA 33 to 35 to based on the light that is detected by the input monitor PD and the output monitor PD to maintain the gain of the optical amplifier at a constant value.

[0141]
Here the reason why control is exerted so that the gain will be level is because the wavelength characteristics will vary if there are variations in gain.

[0142]
Consequently, if a gain equalizer (GEQ) with variable characteristics is used as the equalizer so that changes in the gain by the SOA can adapt to changes in the wavelength characteristics, then by monitoring the output monitor PD82 or the input monitor 81 alone, control so that the output level will be constant can be exerted using an automatic level control circuit (ALC)

[0143]
In addition, when it is desirable to perform control so that the output level is constant while maintaining the wavelength characteristics of the gain through the use of the automatic gain control circuit (AGC) 50, a variable attenuator can be equipped as the input terminal 8 or the output terminal 9 so that the output of the optical amplifier can be maintained at a constant level through controlling either the optical signal level that is injected into the optical amplifier or the output of the optical amplifier even if the gain of the optical amplifier is controlled to a constant gain.

[0144]
Figure 10 is a structure where two fiber grating reflective mirrors (FG-Mirror) containing an optical amplification medium are structured into a Fabry-Perot oscillator when a silica-based erbium-doped fiber is used as the optical amplification medium, and a structure where it is not necessary for the automatic gain control circuit (AGC) to be controlled by the I/O monitors.

[0145]
In Figure 10, 9:1 couplers (CPL) 73 and 74 are equipped in the structure of Figure 6, and the fiber grating mirrors 42 and 43 are equipped in the destination that is divided out using the 9:1 couplers (CLP) 73 and 74.

[0146]
The number 1 9:1 coupler (CPL) 73 is inserted between the multi-wavelength coupler 5 and the number 1 silica-based erbium-doped fiber 21 (EDF1).

[0147]
At the end of the branch of the number 1 9:1 coupler (CPL) 73 is equipped the number 1 fiber grating mirror (FG-Mirror) 42.

[0148]
The number 2 9:1 coupler (CPL) 74 is equipped between the gain equalizer 23 (GEQ 50) and the optical isolator 32.

[0149]

At the end of one of the branches of the number 2 9:1 coupler (CPL) 74 is equipped the number 2 fiber grating mirror (FG-Mirror) 43.

[0150]
Below will be explained an example of operation using the case described above where the structure is an S-band multi-wavelength optical amplifier.

[0151]
First of all, preparations are made so that there is no signal light at the 1530 nm wavelength.

[0152]
The signal is amplified by the silica-based erbium-doped fiber 1, receives gain equalization by the multiple gain equalizers, receives the S-band gain wavelength characteristics such as shown by the white rectangular area in Figure 3, and is outputted.

[0153]
This light that was amplified by the silica-based erbium-doped fiber 1 is outputted 90% to the optical isolator 32 by the number 2 9:1 coupler 74, with the remaining 10% outputted to the fiber grating mirror (FG-Mirror) 43.

[0154]
The fiber grating mirror (FG-Mirror) 43 reflects the 1530 light in the band of wavelengths of 1530 nm ± a few tenths of an nm, and is returned to the silica-based erbium-doped fiber 1 through the number 2 1 coupler 74.

[0155]
The silica-based erbium-doped fiber 1 amplifies the returned light, and 10% of the light is split by the number 1 9:1 coupler 74 and is inputted to the number 1 fiber grating mirror (FG-Mirror) 73 [sic].

[0156]
The fiber grating mirror (FG-Mirror) 42 reflects the 1530 nm light in a band with wavelengths of 1530 nm ± several tenths of an nm, and again returns it to the silica-based erbium-doped fiber 1 through the first 1 coupler 73.

[0157]
This process structures a 1530 nm Fabry-Perot resonator from the two fiber grating mirrors, the two 9:1 couplers (CPL) and the EDF (which is the amplification medium).

[0158]
In this structure, stimulating the EDF forms a population inversion, fulfilling the lasing conditions at the 1530 nm wavelength, producing a 1530 nm laser output.

[0159]

When this lasing occurs, the population inversion ratio is fixed at a single value (and the gain is also fixed), and thus even if the input is changed the gain and the wavelength characteristics of the gain remain constant.

[0160]
When the input signal is strong, then a lot of the excitation light power is expended in amplifying the signal light, and the laser operation at 1530 nm stops.

[0161]
When the laser operation stops, the gain stop being uniform.

[0162]
Here, even though a Fabry-Perot resonance is created by the configuration of the fiber grating in such a way that there is lasing at 1530 nm, the wavelengths that cause population inversion of the energy in the optical amplification medium by the useable wavelengths that pass through the gain equalizer, insofar as it is not a place where the signal light exists, can be anywhere in the S-band.

[0163]
In addition, this resonator structure is not limited to a Farby-Perot resonator, but can also use a ring-shaped resonator.

[0164]
Although the explanation used the example of the S-band, even other bands, if they are in a wavelength that causes a population inversion in the energy in the optical amplification medium using a wavelength that passes through the gain equalizer can be anyplace in the amplification band as long as it is a place where the signal light does not exist.

[0165]
In addition, when the gain equalizer is structured as is shown in Figure 4, the greater part of the gain that is generated by the population inversion is discarded, and so a gain equalizer that passes wavelengths in a portion of the region that is discarded can be constructed and the wavelengths that are reflected by the fiber grating mirror can be selected to resonate with these wavelengths.

[0166]
The reasons why the gain of the signal light due to the lasing is uniform are explained using Figures 11 and 12.

[0167]
Figure 11 explains the case where the gain characteristics due to the lasing in the C-band optical amplifier are uniform.

[0168]
The C-band light signal is input at 1552 nm and the light is amplified by the optical amplification medium.

[0169]
As with Figure 10, both ends of the optical amplification medium are equipped with optical couplers, where, at the end of the branch of each there is a fiber grating mirror that reflects light at 1530 nm, forming a resonator and making it possible to confirm lasing at 1530 nm.

[0170]
Figure 12 is a graph of gain measurements converted from the levels at which the signal light is input into the optical amplification medium using a light signal at the 1552 nm wavelength, as was done in Figure 11.

[0171]
The characteristics marked with the circles in the diagram are those characteristics where there is no resonator and no lasing, and it can be seen that the gain changes as the input level changes.

[0172]
The characteristic line marked with the squares shows the characteristics when an oscillator is constructed with the optical amplification media that resonates with 1530 nm, and lasing occurs.

[0173]
In this characteristic line, the gain is constant over a broad input range from -35 dBm to -10 dBm even if the input level changes.

[0174]
Figure 12 is that of stopping the laser operation at about input -7 dBm.

[0175]
Figure 13 shows an example of a case of a broad band optical amplifier using this invention.

[0176]
A multi-wavelength optical signal comes in through a transmission on a transmission path 57 made from an optical fiber.

[0177]
The transmission path 57 can use a single-mode fiber SMF (a zero-dispersion 1.3 μm fiber), a dispersion-compensation fiber (a fiber that has a negative dispersion value relative to the SMF), a dispersion-shifted fiber DSF (a fiber where the zero-dispersion value is in the signal wavelength band for the transmission), and a non-zero dispersion shifted fiber NZ-DSF (a fiber where the zero-dispersion value is provided adjacent to the wavelength band for the signals that are used for transmission).

[0178]

The transmission path 57 is excited by the excitation light source 56 through the multi-wavelength coupler 66 to perform Raman amplification in order to perform distributed amplification on the transmission path, thereby improving the noise figure (NF) when amplifying after partitioning by each wave band region in the later stages.

[0179]
The multi-wavelength optical signals that are amplified by the excitation light source 56 are divided into the various wavelength bands (the L-band, the C-band, and the S-band) by the WDM filter.

[0180]
The light is input into the L-band optical amplifier 60, the C-band optical amplifier 61, and the S-band optical amplifier 62, respectively, and each amplifies the respective light signals.

[0181]
The C-band optical amplifier 61 is structured from the L-band [sic] optical amplification units 61-1 and 61-2, the splitting coupler 75, the dispersion-compensation fiber 53, the variable attenuator 52, the automatic gain control circuit 50, and the automatic level control circuit 51.

[0182]
For the C-band optical amplifier units 61-1 and 61-2 the population inversion ratio is put to about 0.7 by the automatic gain control circuit 50 and amplification with little difference in gain between 1530 μm and 1570 μm [sic] is achieved by maintaining a constant gain.

[0183]
The dispersion-compensation fiber 53 is provided to compensate for dispersion in the transmission path.

[0184]
The variable optical attenuator 52 is controlled by the automatic level control circuit 51 to attenuate the output of the C-band optical amplifier unit 61-1 so that the output of the C-band optical amplifier unit 61 is a constant value.

[0185]
The L-band optical amplifier 60 is structured from the L-band optical amplification units 60-1 and 60-2, the splitting coupler 75, the dispersion-compensation fiber 53, the variable attenuator 52, the automatic gain control circuit 50, and the automatic level control circuit 51.

[0186]
The L-band optical amplifier units 60-1 and 60-2 are given a low population inversion ratio by the automatic gain control circuit 50 and even though the gain is suppressed to a constant level, the length of the EDF (which is the amplification medium) is adjusted so

that the gain between 1570 nm and 1610 nm will be the same as for the C-band amplifier unit.

[0187]
The dispersion-compensation fiber 53 is provided to compensate for dispersion in the transmission path.

[0188]
The variable optical attenuator 52 is controlled by the automatic level control circuit 51 to attenuate the output of the L-band optical amplifier unit 60-1 so that the output of the L-band optical amplifier unit 60 is a constant value.

[0189]
The S-band optical amplifier 62 is structured from the S-band optical amplification units 62-1 and 62-2, the splitting coupler 75, the dispersion-compensation fiber 53, the variable attenuator 52, the automatic gain control circuit 50, and the automatic level control circuit 51.

[0190]
The S-band optical amplifier units 62-1 and 62-2 are given a low population inversion ratio by the automatic gain control circuit 50 and even though the gain is suppressed to a constant level, the length of the EDF (which is the amplification medium) is adjusted so that the gain between 1590 nm and 1530 nm will be the same as for the C-band amplifier unit.

[0191]
Also, when it comes to these S-band optical amplifier units 62-1 and 62-2, the structures of all of the other examples of embodiment of this invention and wavelength bands apply.

[0192]
The dispersion-compensation fiber 53 is provided to compensate for dispersion in the transmission path.

[0193]
The variable optical attenuator 52 is controlled by the automatic level control circuit 51 to attenuate the output of the L-band optical amplifier unit 60-1 [sic] so that the output of the S-band optical amplifier unit 62 is a constant value.

[0194]
The outputs of the L-band optical amplifier 60, the C-band optical amplifier 61, and the S-band optical amplifier 62 are output to the multi-wavelength transmission path by the WDM (wavelength-divided multiplexer) coupler 55.

[0195]

In Figure 13 the explanation was based on a combination of the S-band, the conventional L-band, and the C-band, but combinations can also be made with the other wavelength bands described in Figure 1.

[0196]
This invention is not limited to the 3 wavelength bands that comprised the specific example of embodiment, but can apply to any combination of two or more wavelength bands.

[0197]
[Effects of the Invention]
An optical amplifier that has practical gain in the S-band, the S+- band, and the L+- band can be achieved using silica-based erbium-doped fibers (EDF) by increasing the population inversion ratio of the optical amplification medium, expanding the band width over which gain is produced by the optical amplification medium, by equalizing over this band width so as to be able to obtain flat gain characteristics at a position that is not the position of the peak value (the gain characteristic offset slope), and by selecting the length of the rough clothing [sic: amplification] medium for the light based on the gain characteristics of the gain equalizer and the optical amplification medium to obtain the desired gain value.

[0198]
Additionally, the conversion efficiency for converting from excited light to the signal light can be improved by dividing the optical amplification medium into multiple segments and dividing the gain equalizer between the various optical amplification media segments to place them in a distributed or dispersed arrangement.

[0199]
In addition, similar improvements to the conversion efficiency can be obtained by a structure where the gain equalizers are laid out in a distributed fashion in the gain equalization by providing a grating in the optical wave guide part of the optical amplification medium when the optical amplification medium can be structured into a small form.

[0200]
Because of this, this invention will make optical fiber amplifiers possible for new bands aside from C-band and L-band, and will contribute to an increase in capacity.

[Simple Explanation of the Figures]
Figure 1 shows bands that can be amplified in an optical fiber amplifier.
Figure 2 shows the wavelength characteristics of gain in silicon-based erbium-doped fibers (EDF) and population inversion rates.
Figure 3 shows the extraction and equalization of S-band gain from Figure 2, showing the gain-wavelength characteristics when the population inversion ratio is 0.9.
Figure 4 is a figure showing the wavelength characteristics of the gain equalizer.
Figure 5 shows the first example of embodiment.

Figure 6 shows the second example of embodiment.
Figure 7 shows the third example of embodiment.
Figure 8 is a figure showing the gain characteristics of a semiconductor optical amplifier.
Figure 9 shows the fourth example of embodiment.
Figure 10 shows the fifth example of embodiment.
Figure 11 shows the spectral characteristics when lasing.
Figure 12 is a figure for explaining the principles behind the constant gain produced by lasing.
Figure 13 shows a broad-band amplifier using this invention.

[Explanation of Symbols]
1, 11, 12, and 13 are silica-based erbium-doped fibers (EDF)
2, 21, 22, and 21 [sic] are gain equalizers (GEQ)
31, and 32 are optical isolators
33, 34, and 35 are optical semiconductor amplifiers
4 is an excitation light source
5 is a multi-wavelength coupler
8 is an input terminal
9 is an output terminal
71, 72, 73, and 74 are optical splitter couplers
81 is an input monitor PD (photodiode)
82 is an output monitors PD (photodiode)
50 is a gain control circuit (AGC)
42 and 43 are fiber grating mirrors

[Document Name] Abstract

[Abstract]

[Topic]

To make it possible to use in optical transmission bands aside from the bands used in existing optical amplifiers by expanding the amplification bands using existing optical amplification media.

[Method of Solution]

A flat gain in a wavelength band different from the gain peak value is obtained by providing an optical amplification medium for amplifying light with excited emission through excitation an excitation method that provides excitation that generates at least one gain peak, and providing a gain equalizer that equalizes the gain peak of the optical amplification medium.

In order to improve the amplification conversion efficiency, the optical amplification medium is provided with a gain equalization method distributed or dispersed along the lengthwise direction, thus improving the conversion efficiency of the optical amplification.

[Selected Figure]

Figure 6

File Number: 00-00088

[Document Name] Figures
[Figure 1]

[see source for figure]

[Figure 2]

[see source for figure]

[Figure 3]

[see source for figure]

[Figure 4]

[see source for figure]
[VERTICAL AXIS] Transmittance
[IN FIGURE] Excitation Band
[HORIZONTAL AXIS] Wavelength (nm)

[Figure 5]

[see source for figure]
[TITLE] Silica-based Erbium-doped Fiber (EDF)
[UPPER LEFT] Input
[UPPER RIGHT] Output
[MIDDLE] 0.98 μm excitation laser diode
[LOWER LEFT] Input monitor photodiode
[LOWER RIGHT] Output monitor photodiode

[Figure 6]

[see source for figure]
[TOP] Silica-based Erbium-doped Fiber 1
[UPPER LEFT] Optical Splitter
[CENTER] 0.98 μm excitation laser diode
[LOWER LEFT] Input monitor photodiode
[LOWER RIGHT] Output monitor photodiode

[Figure 7]

[see source for figure]
14 Core

15 Clad
16 Grating
[LOWER LEFT] Input
[LOWER RIGHT] Output

[Figure 8]

[see source for figure]

[Figure 9]

[see source for figure]
[TOP] Semiconductor Optical Amplifier
[UPPER LEFT] Optical splitter
[LOWER LEFT] Input monitor photodiode
[LOWER RIGHT] Output monitor photodiode

[Figure 10]

[see source for figure]
[TOP] Silica-based Erbium-doped Fiber 1
[LEFT] Optical Splitter

[Figure 11]

[see source for figure]

[Figure 12]

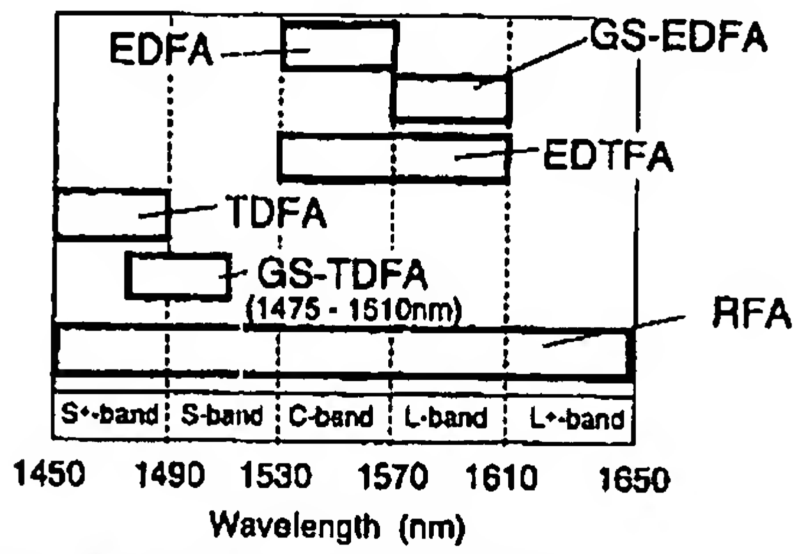
[see source for figure]
[TOP] With no lasing
[MIDDLE] With lasing

[Figure 13]

[see source for figure]
57 Transmission path
56 Excitation

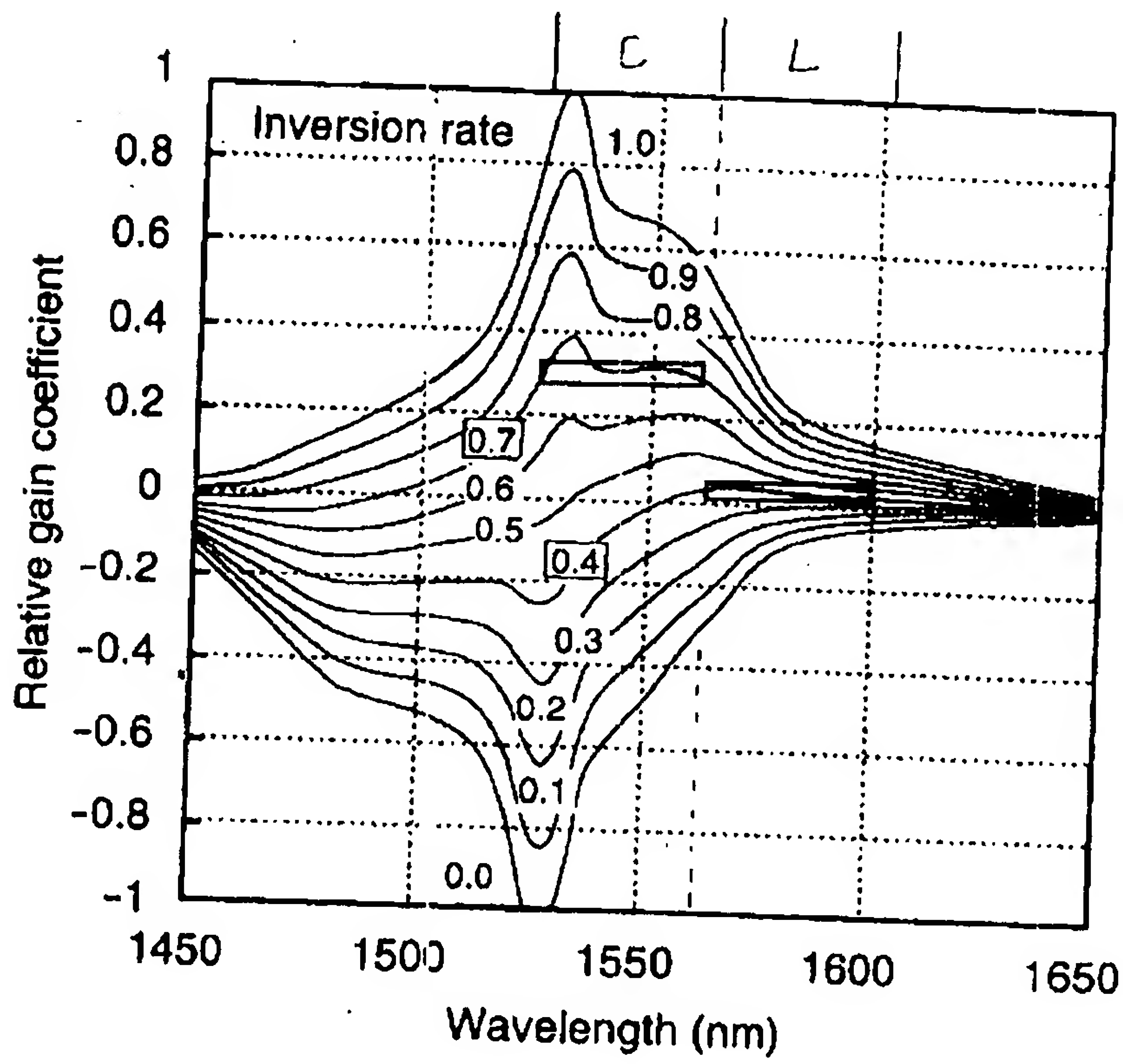
【書類名】　図面

【図１】



EDFA : Erbium-Doped Fiber Amplifier (1530 - 1570 nm)
GS-EDFA : Gain-Shifted EDFA (1570-1610 nm)
EDTFA : Tellurite-Based EDFA (1530 - 1610 nm)
TDFA : Thulium-Doped Fluoride-Based Fiber Amplifier (1450 - 1490 nm)
RFA : Raman Fiber Amplifier (1450 - 1650 nm or more)

【図2】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0.8
0.7
0.6
0.5
0.4
0.3
0.2
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1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
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Relative gain coefficient
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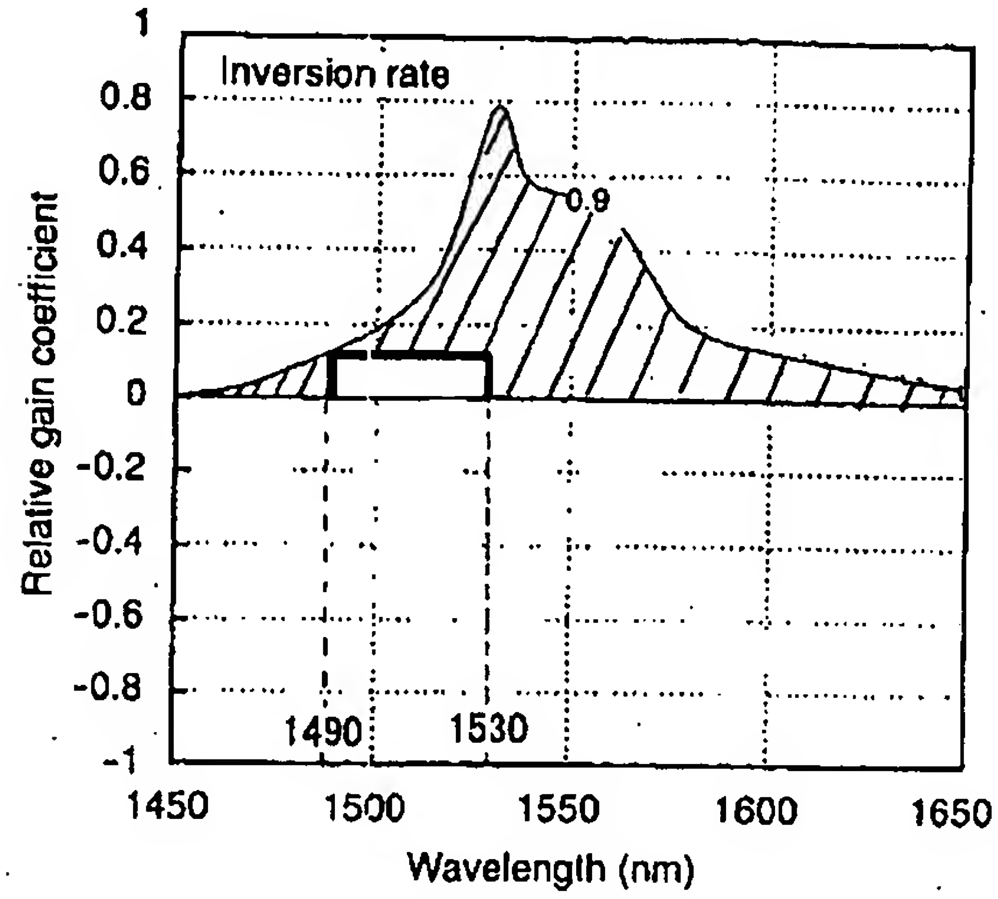
1550
1600
1650
Wavelength (nm)

【図3】


Inversion rate
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Relative gain coefficient
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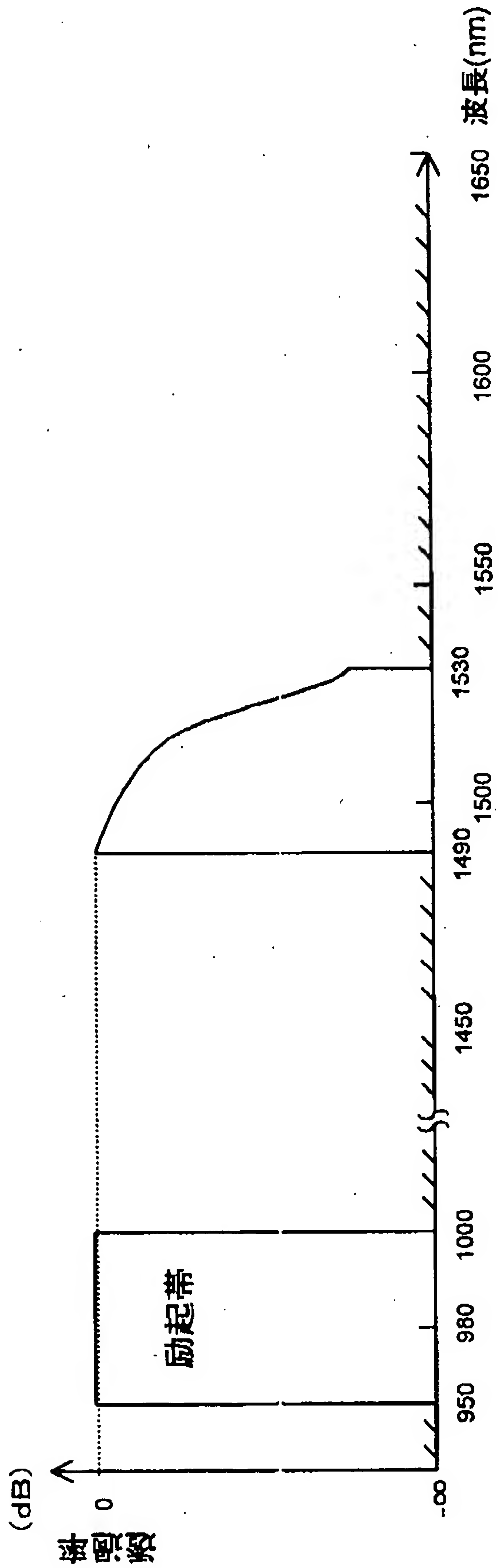
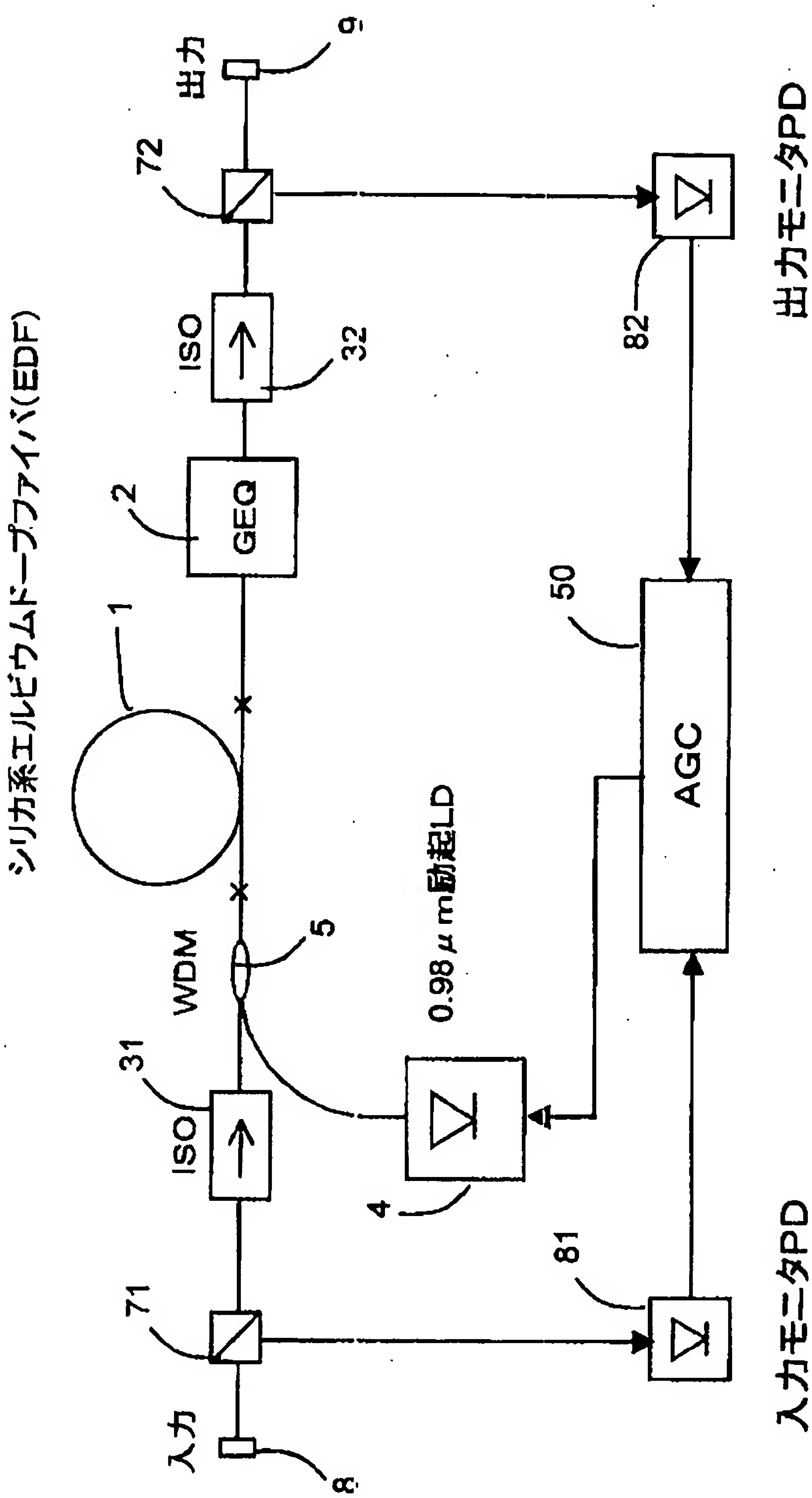
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1490
1530
1450
1500
1550
1600
1650
Wavelength (nm)

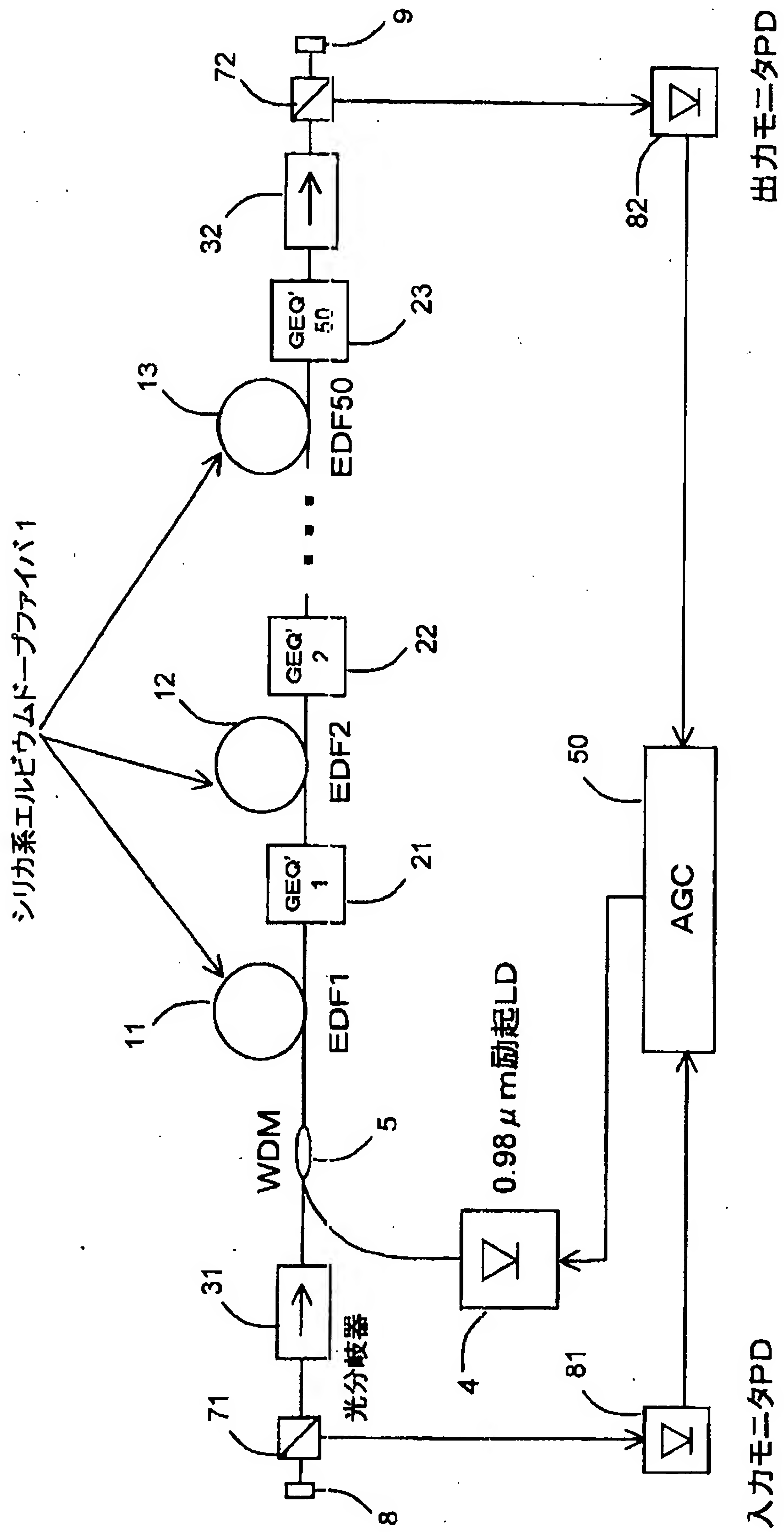
【図４】


波長(nm)
1650
1600
1550
1530
1500
1490
1450
1000
980
950
励起帯
透過率
(dB)
0
-∞

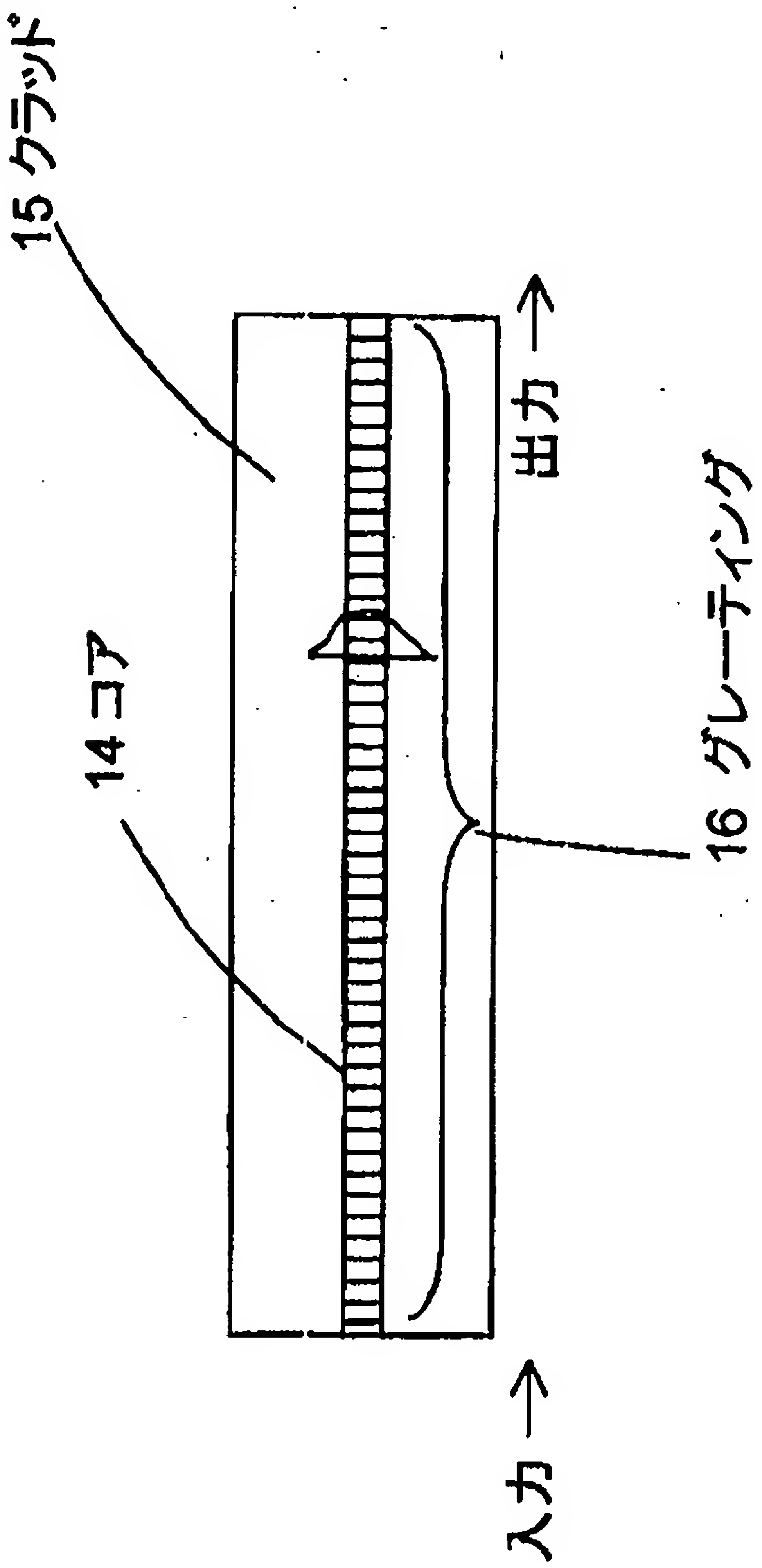
【図５】


出力
9
72
ISO
32
2
GEQ
1
シリカ系エルビウムドープファイバ(EDF)
WDM
5
0.98μm励起LD
31
ISO
4
71
入力
8
81
82
50
AGC
出力モニタPD
入力モニタPD

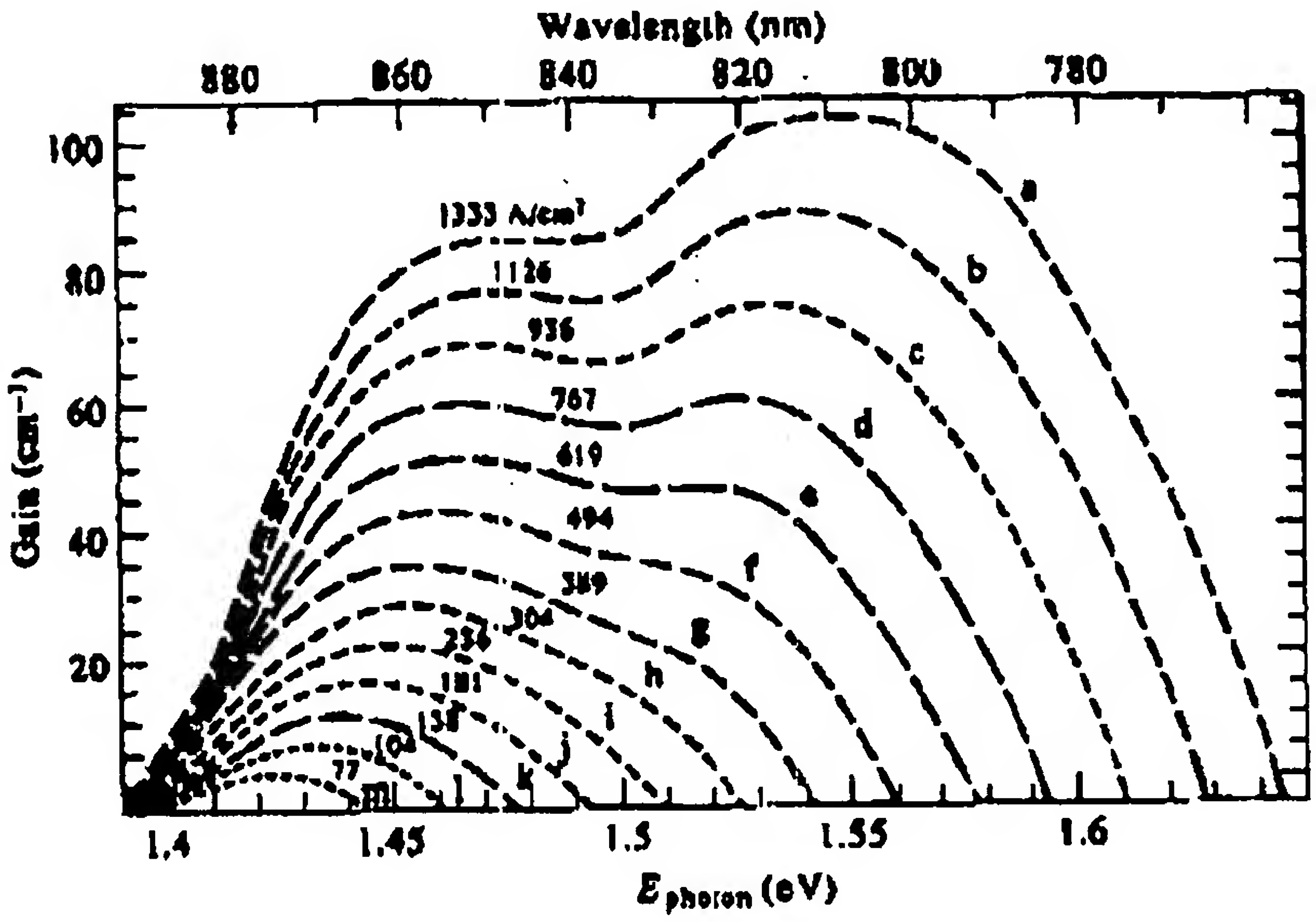
【図６】


シリカ系エルビウムドープファイバ1
8
71
光分岐器
31
WDM
5
0.98μm励起LD
4
11
EDF1
GEQ' 1
21
12
EDF2
GEQ' 2
22
13
EDF50
GEQ' 50
23
32
72
9
入力モニタPD
81
AGC
50
出力モニタPD
82

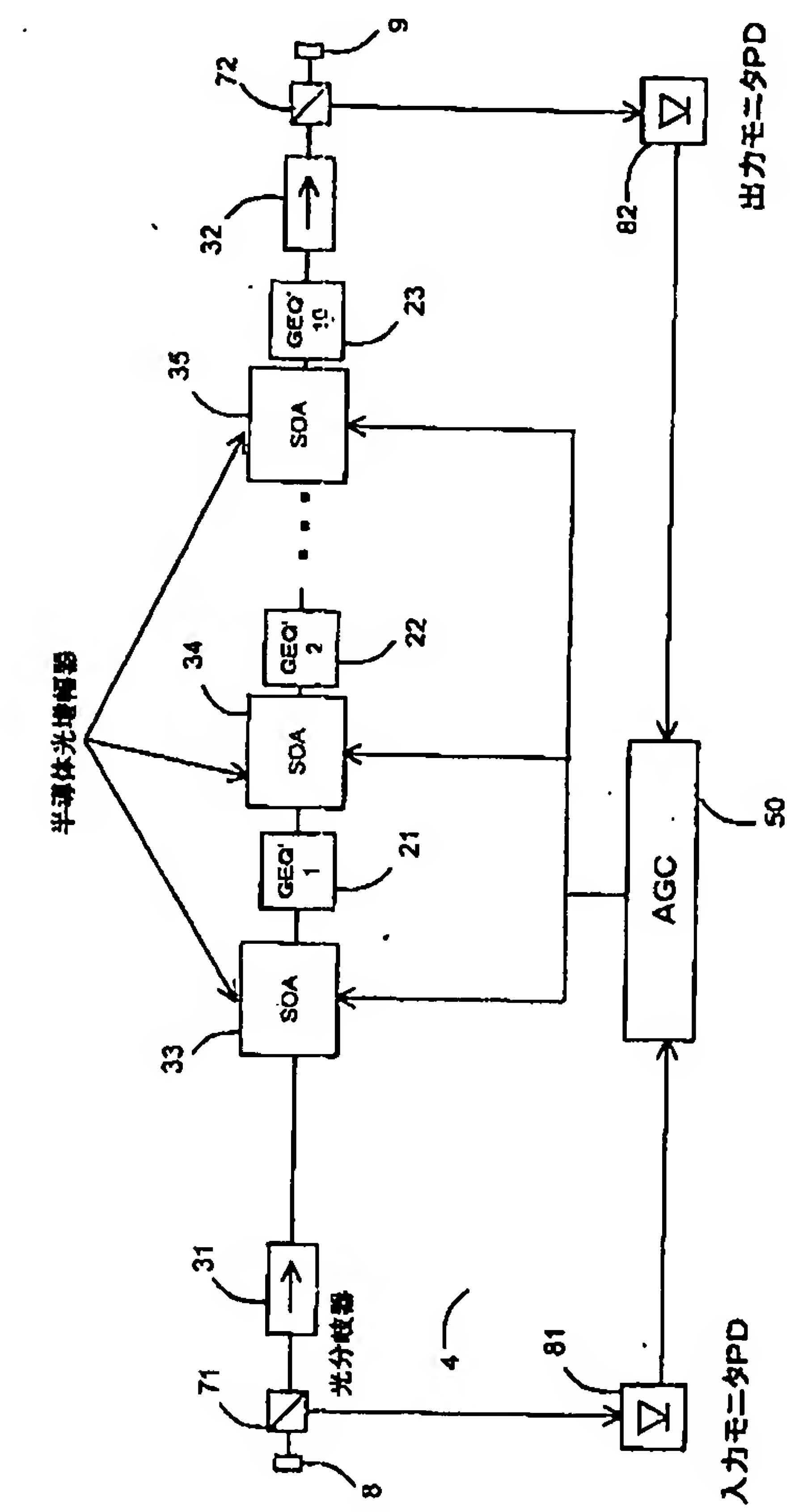
【図７】



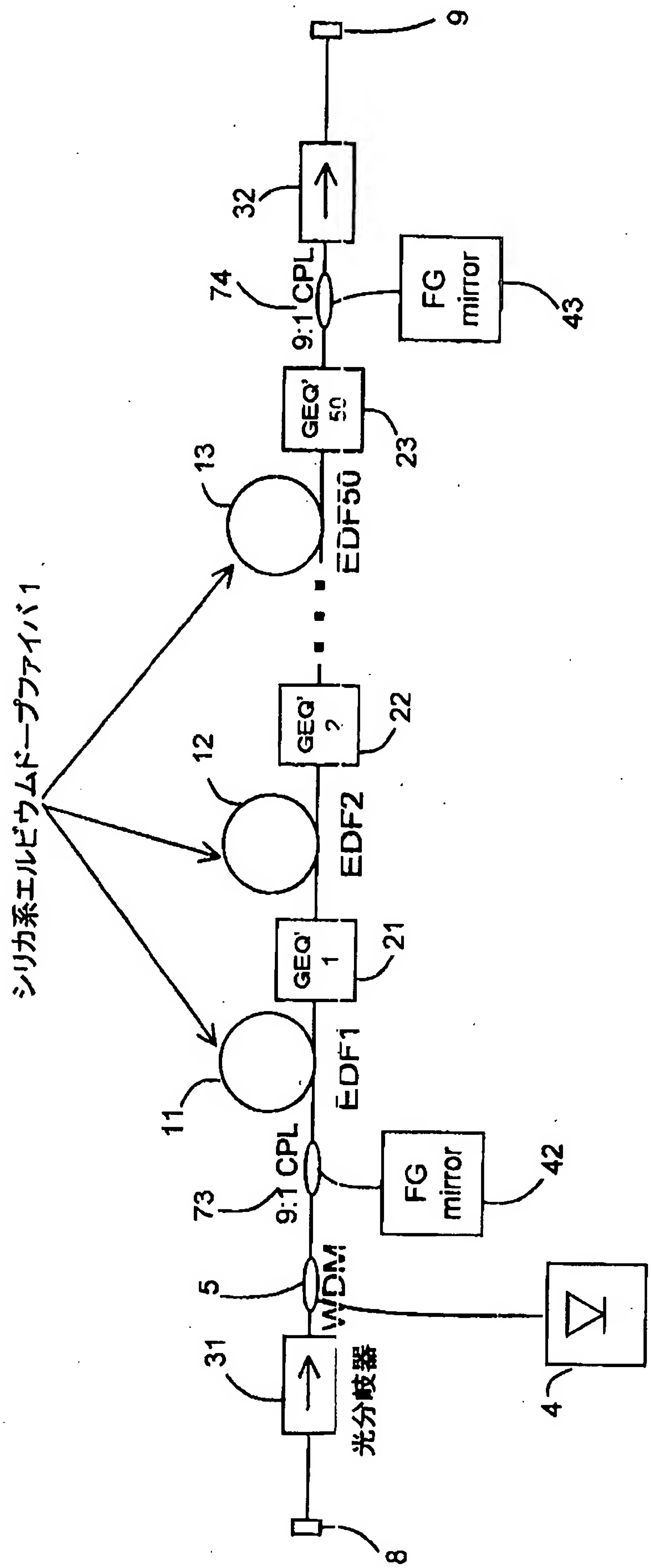
【図８】


Wavelength (nm)
880
860
840
820
800
780
100
80
60
40
20
Gain (cm⁻¹)
1333 A/cm²
1126
936
767
619
494
389
304
234
181
138
104
77
a
b
c
d
e
f
g
h
i
j
k
l
m
1.4
1.45
1.5
1.55
1.6
E photon (eV)

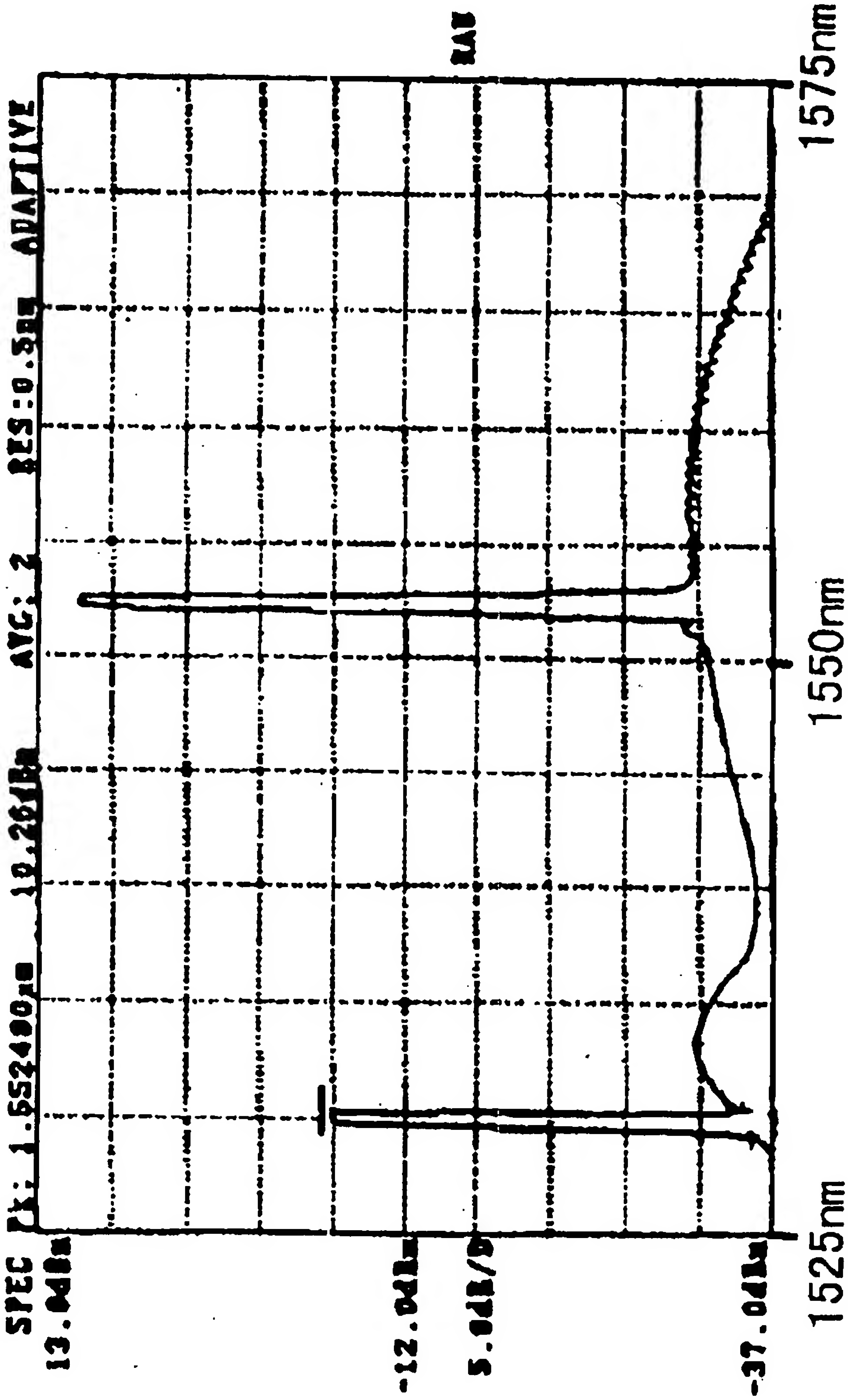
【図９】


半導体光増幅器
SOA
SOA
SOA
GEQ' 1
GEQ' 2
GEQ' 10
AGC
光分岐器
出力モニタPD
入力モニタPD
8
9
71
72
31
32
33
34
35
21
22
23
4
50
81
82

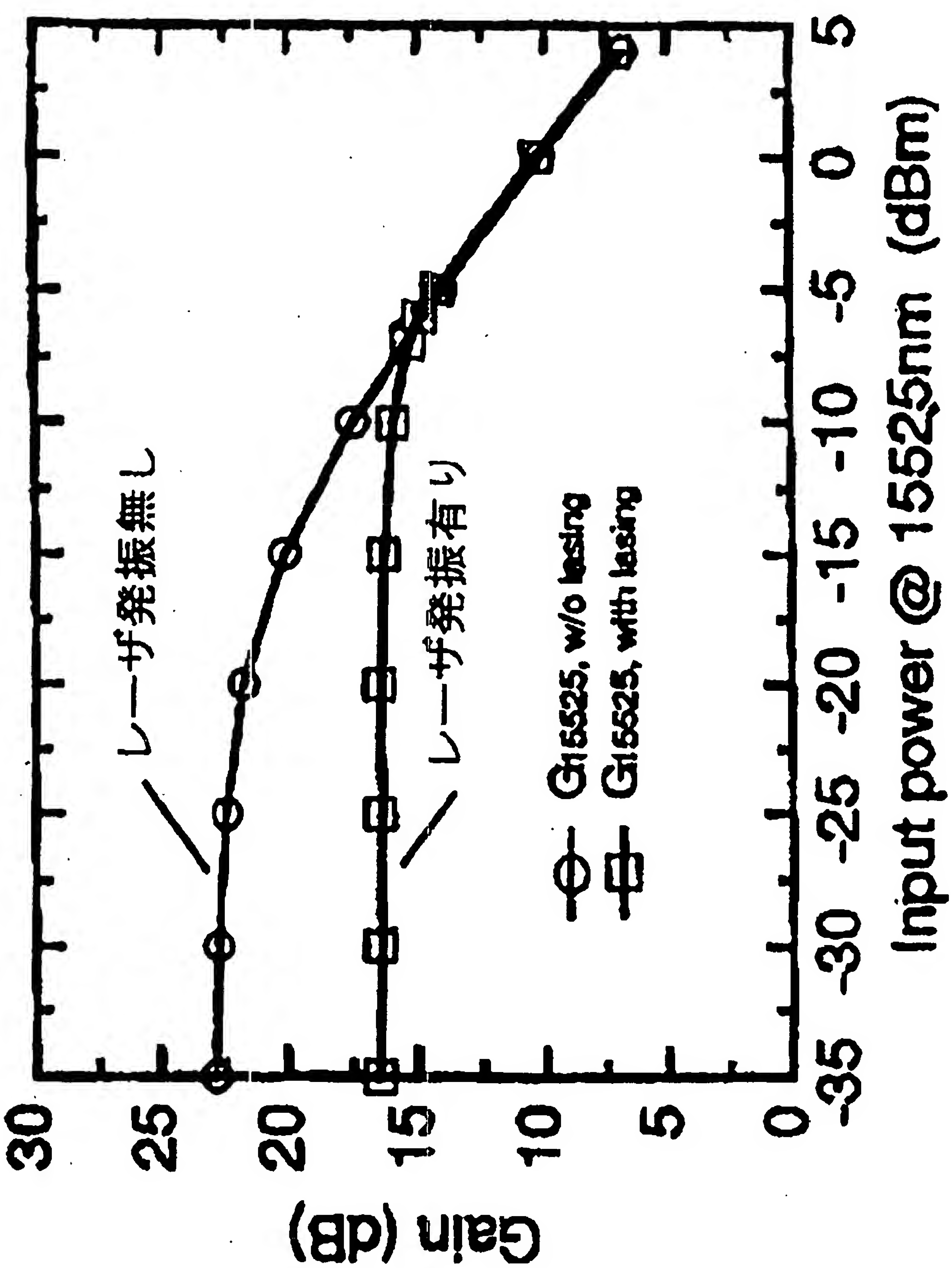
【図１０】


シリカ系エルビウムドープファイバ1
光分岐器
WDM
9:1 CPL
FG
mirror
EDF1
GEQ'
1
EDF2
GEQ'
2
EDF50
GEQ'
50
9:1 CPL
FG
mirror
8
31
5
4
73
42
11
21
12
22
13
23
74
43
32
9

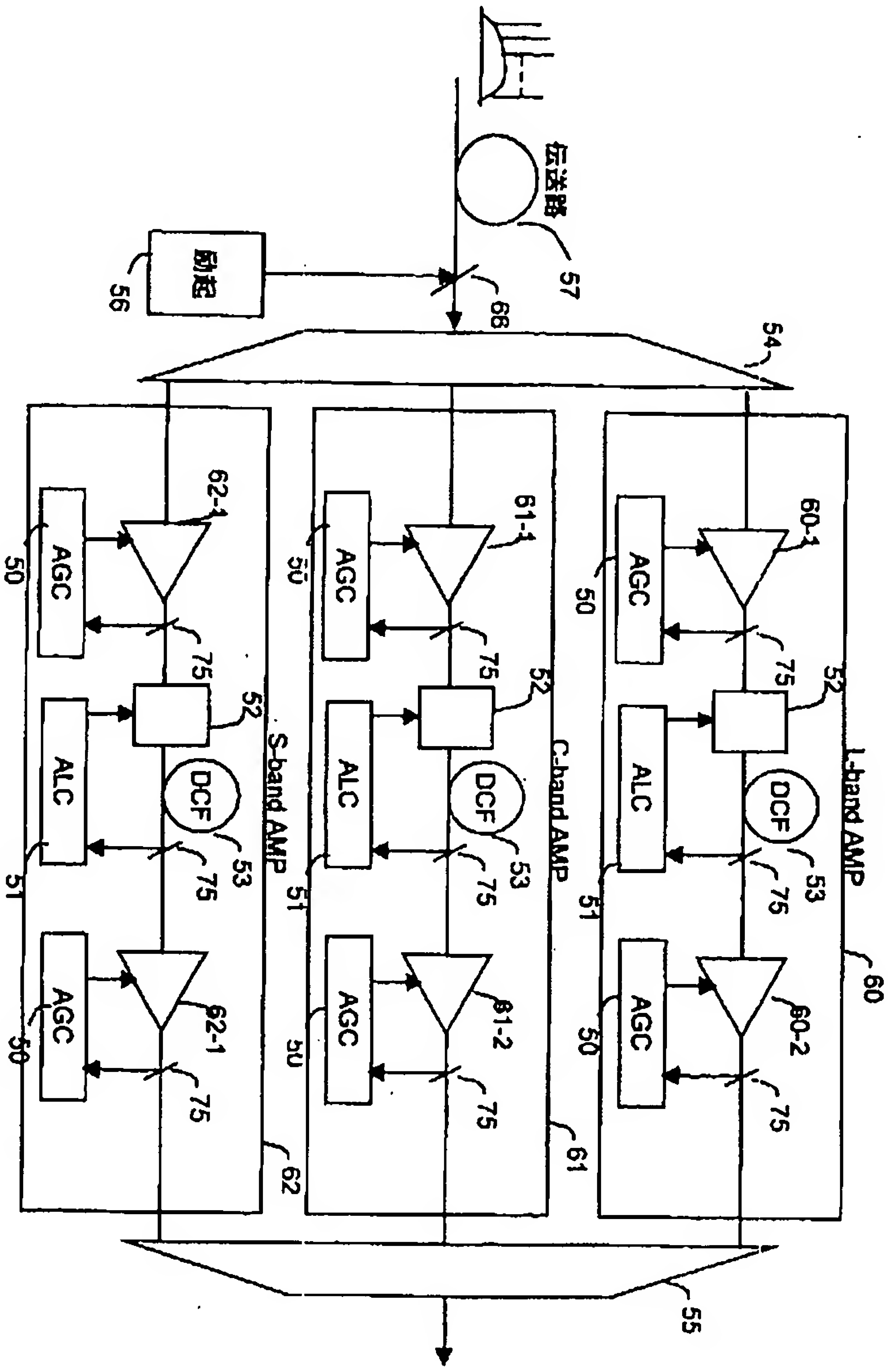
【図１１】


SPEC
13.0dBm
-12.0dBm
5.0dB/D
-37.0dBm
ADAPTIVE
RES:0.5nm
AVG: 2
10.26dBm
PK: 1.552490μm
RAW
1575nm
1550nm
1525nm

【図１２】


レーザ発振無し
レーザ発振有り
G15525, w/o lasing
G15525, with lasing
Gain (dB)
30
25
20
15
10
5
0
-35
-30
-25
-20
-15
-10
-5
0
5
Input power @ 15525nm (dBm)

【図１３】


伝送路
57
励起
56
68
54
AGC
ALC
DCF
AGC
S-band AMP
C-band AMP
L-band AMP
62-1
61-1
61-2
60-1
60-2
50
51
52
53
75
60
61
62
55